Part – 1: Introduction, Position, Distance and Displacement

Learning Objectives

After studying this part, you will be able to:

- Define motion and rest.
- Understand the concept of a reference frame.
- Differentiate between scalar and vector quantities.
- Explain position, path length, distance, and displacement.
- Solve basic conceptual problems related to one-dimensional motion.

---

1. Introduction

Motion is one of the most fundamental concepts in Physics. Every object around us is either at rest or in motion.

Examples:

- A car moving on a highway.
- A train running on a track.
- A falling stone.
- The Earth revolving around the Sun.

The study of motion without considering its causes is called **Kinematics**.

---

2. What is Motion?

Motion is the change in the position of an object with time relative to a chosen reference point.
If the position changes with time, the object is said to be **in motion**.
If the position remains unchanged with time, the object is said to be **at rest**.

---

3. Reference Frame

Motion and rest are **relative concepts**.
A **reference frame** (or frame of reference) is a point or coordinate system with respect to which the position of an object is measured.

Examples

- A passenger sitting inside a moving train is **at rest** with respect to the train.
- The same passenger is **in motion** with respect to a person standing on the platform.

Conclusion: Motion depends on the chosen reference frame.

---

4. Point Object

An object may be treated as a **point object** if its size is negligible compared with the distance travelled.

Examples

- A train travelling from Delhi to Mumbai.
- The Earth revolving around the Sun.
- An aircraft flying between two cities.

In these cases, the dimensions of the object are much smaller than the distance covered.

---

5. Scalar and Vector Quantities

Scalar Quantity

A scalar quantity has **magnitude only**.
Examples:

- Distance
- Speed
- Time
- Mass
- Temperature
- Energy

Vector Quantity

A vector quantity has **both magnitude and direction**.
Examples:

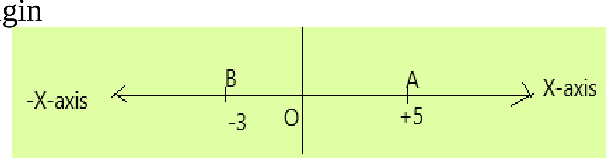
- Displacement
- Velocity
- Acceleration
- Force
- Momentum

---

6. Position of an Object

The **position** of an object is its location relative to a chosen origin.
For motion in a straight line, the position is represented by the coordinate axes.

- Positive direction → Right of the origin
- Negative direction → Left of the origin



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7. Distance

Definition:

Distance is the **total length of the actual path travelled** by an object.

Characteristics

- Scalar quantity
- Always positive
- Depends on the path followed
- SI Unit: metre (m)

Example

A person walks:

- 5 m east
- then 3 m west

Distance travelled:
5+3= 8
Answer: 8 m

---

8. Displacement

Definition:

Displacement is the **shortest straight-line distance** from the initial position to the final position, along with direction.

Characteristics

- Vector quantity
- May be positive, negative, or zero
- Depends only on the initial and final positions
- Independent of the path followed
- SI Unit: metre (m)

Example

A person walks:

- 5 m east
- then 3 m west

Net displacement:
$5-3=2$
Answer: 2 m east

---

9. Difference Between Distance and Displacement

Distance	Displacement
Scalar quantity	Vector quantity
Depends on actual path	Depends only on initial and final positions
Always positive	Can be positive, negative, or zero
Distance ≥ Magnitude of displacement	Magnitude ≤ Distance

---

10. Special Cases

Case 1

If an object moves only in one direction,
Distance = Magnitude of Displacement
Example:
Move 15 m east.
Distance = 15 m
Displacement = 15 m east

Case 2

If an object returns to its starting point,
Distance > 0
Displacement = 0
Example:
Move 10 m east and then 10 m west.
Distance = 20 m
Displacement = 0

---

11. Conceptual Questions

Q1. Can distance ever be negative?
Answer: No. Distance is always positive or zero.

Q2. Can displacement be zero even when distance is not zero?
Answer: Yes. This happens when the object returns to its starting point.

Q3. Can distance and displacement have the same numerical value?
Answer: Yes, when the object moves in a straight line without changing direction.

---

12. Important Formulae

For one-dimensional motion:

- **Distance** = Total path length
- **Displacement**

$$\boxed{\Delta x = x_f - x_i}$$

where:

- x_i = Initial position
- x_f = Final position

---

13. Exam Tips (★★★★★)

- Always distinguish between **distance** and **displacement**.
- Remember that **distance is a scalar**, whereas **displacement is a vector**.
- Draw a clear number line while solving displacement problems.
- In Board and NEET exams, conceptual questions on **distance vs displacement** are frequently asked.

Part – 2: Speed, Velocity and Types of Motion

Learning Objectives

After studying this part, you will be able to:

- Define speed and velocity.
- Distinguish between average and instantaneous quantities.
- Differentiate between speed and velocity.
- Understand uniform and non-uniform motion.
- Solve basic numerical problems related to speed and velocity.

---

1. Speed

Definition

Speed is the distance travelled by an object per unit time.
It tells us **how fast** an object is moving, irrespective of its direction.

Formula

=

$$\boxed{speed = \frac{distance}{time}}$$

Or,

$$\boxed{v = \frac{d}{t}}$$

where,

- v = Speed
- d = Distance travelled
- t = Time taken

SI Unit

$\boxed{ms^{-1}}$

Other Common Units

- km h^{-1}
- cm s^{-1}

Unit Conversion

$$\boxed{1ms^{-1} = 3.6kmh^{-1}}$$

$$\boxed{1kmh^{-1} = \frac{5}{18}ms^{-1}}$$

2. Average Speed

Average speed is the **total distance travelled divided by the total time taken**.

$$\boxed{\boldsymbol{Average\ Speed = \frac{Total\ Distance}{Total\ Time}}}$$

Example

A car travels 120 km in 2 h and 180 km in 3 h.
Total distance: 120+180 = 300 km
Total time: 2+3 = 5 h
Average speed: 300/5=60 km/h
Answer: 60 km h^{-1}

---

3. Instantaneous Speed

Definition

The speed of an object **at a particular instant of time** is called instantaneous speed.

Examples

- Speed shown by a car's speedometer.
- Speed of a runner at a specific moment.

Instantaneous speed may change continuously in non-uniform motion.

---

4. Velocity

Definition

Velocity is the displacement covered per unit time in a specified direction.
It tells us **how fast and in which direction** an object is moving.

Formula

$$\boxed{\text{Velocity} = \frac{\text{Displacement}}{\text{Time}}}$$

Or

$$\boxed{v = \frac{\Delta x}{\Delta t}}$$

where,

- Δx = Displacement
- Δt = Time interval

SI Unit

metre per second (m/s)

---

5. Average Velocity

Definition

Average velocity is the **total displacement divided by the total time taken**.

Formula

$$\boxed{\text{Average Velocity} = \frac{\text{Total displacement}}{\text{Total Time}}}$$

Example

A person walks 40 m east and then 10 m west .

Time taken = 10 s
Net displacement: 40−10=30 m east
Average velocity: 30 / 10 = 3 m/s east
Answer: 3 m s⁻¹ east

---

6. Instantaneous Velocity

Definition

The velocity of an object **at a particular instant of time** is called instantaneous velocity.
Mathematically,

$$\boxed{v = \frac{dx}{dt}}$$

This is the slope of the **position–time graph** at that instant.

---

7. Difference Between Speed and Velocity

Speed	Velocity
Scalar quantity	Vector quantity
Depends on distance	Depends on displacement
No direction	Has direction
Always positive or zero	Can be positive, negative, or zero
Never decreases due to direction alone	Changes if direction changes

---

8. Uniform Motion

Definition

An object is said to be in **uniform motion** if it covers **equal distances in equal intervals of time**.

Characteristics

- Constant speed
- Constant velocity (if direction is unchanged)
- Zero acceleration

Example

A train is moving at **20 m s⁻¹** along a straight track.

---

9. Non-Uniform Motion

Definition

An object is in **non-uniform motion** if it covers **unequal distances in equal intervals of time** or **equal distances in unequal intervals of time**.

Characteristics

- Variable speed
- Variable velocity
- Acceleration is non-zero

Examples

- A freely falling stone.

- A car moving in city traffic.

---

10. Solved Examples

Example 1

A cyclist travels **150 m** in **30 s**. Find the speed.

Solution

V = s / t =150/30 =5 m/s

Answer: 5 m s^{-1}

Example 2

A person walks **60 m east** and then **20 m west** in **20 s**.
Find:
(a) Distance
(b) Displacement
(c) Average speed
(d) Average velocity

Solution

Distance: 60+20 = 80 m
Displacement: 60−20 = 40 m east
Average speed: 80 / 20 =4 m/s
Average velocity: 40 / 20 =2 m/s east

---

11. Graphical Interpretation

Position–Time Graph

Uniform Motion

- Straight line
- Constant slope
- Constant velocity

Non-Uniform Motion

- Curved line
- Changing slope
- Changing velocity

---

12. Exam Tips (★★★★★)

- Do **not** confuse **average speed** with **average velocity**.
- Always calculate **distance** for average speed and **displacement** for average velocity.
- Remember: **Average speed is always greater than or equal to the magnitude of average velocity.**
- In a **position–time graph**, the **slope represents velocity**.

Part – 3: Acceleration and Graphical Representation of Motion

Learning Objectives

After studying this part, you will be able to:

- Define acceleration and its SI unit.
- Differentiate between uniform and non-uniform acceleration.
- Understand positive, negative, and zero acceleration.
- Explain retardation (deceleration).
- Interpret position–time, velocity–time, and acceleration–time graphs.

---

1. Acceleration

Definition

Acceleration is the rate of change of velocity with respect to time.
It tells us **how quickly the velocity of an object changes**.

Formula

$$\boxed{a = \frac{\Delta v}{\Delta t} = \frac{v - u}{t}}$$

where,

- u = Initial velocity
- v = Final velocity
- t = Time taken
- a = Acceleration

SI Unit

$$\boxed{\text{metre per second squared } (\mathrm{m\ s^{-2}})}$$

Dimensions

$$\boxed{[LT^{-2}]}$$

---

2. Types of Acceleration

(A) Uniform Acceleration

An object is said to have **uniform acceleration** if its velocity changes by **equal amounts in equal intervals of time**.

Characteristics

- Acceleration remains constant.
- Velocity changes uniformly.
- Velocity–time graph is a straight line.

Examples

- A freely falling object (ignoring air resistance).
- A car increasing its speed at a constant rate.

(B) Non-Uniform Acceleration

Acceleration is **non-uniform** if the velocity changes by **unequal amounts in equal intervals of time**.

Characteristics

- Acceleration is variable.
- Velocity changes irregularly.
- Velocity–time graph is a curve.

Examples

- A car moving in heavy traffic.
- A cyclist on a hilly road.

---

3. Positive, Negative and Zero Acceleration

(A) Positive Acceleration

Velocity increases with time.
Example:
A car speeds up from **10 m s^{-1}** to **20 m s^{-1}**.

$$a < 0$$

(B) Negative Acceleration (Retardation)

Velocity decreases with time.
Example:
A bus slows down before reaching a bus stop.

$$a < 0$$

(C) Zero Acceleration

Velocity remains constant.
Example:
A train is moving at a constant speed in a straight line.

$$a = 0$$

---

4. Retardation (Deceleration)

Definition

Retardation is the negative acceleration that reduces the speed of an object.

Formula

$$\boxed{a = \frac{v-u}{t}}$$

If v < u, then acceleration is negative.

Example

A car slows from **25 m s^{-1}** to **15 m s^{-1}** in **5 s**.

a = (15−25) / 5 = - 2 ms^{-2}
Answer: Retardation = **2 m s^{-2}** (Acceleration = −2 m/s^2

---

5. Position–Time (x–t) Graph

A position–time graph shows how the position of an object changes with time.

(A) Object at Rest

- Horizontal straight line.
- Position remains constant.

Figure to Draw:

- Horizontal line parallel to the time axis.

(B) Uniform Motion

- Straight line with constant positive slope.

Slope = Velocity

$$\boxed{\text{Slope} = \frac{\Delta x}{\Delta t} = v}$$

(C) Non-Uniform Motion

- Curved graph.
- Slope changes continuously.

This indicates changing velocity.

---

6. Velocity–Time (v–t) Graph

A velocity–time graph shows how velocity changes with time.

(A) Constant Velocity

- Horizontal straight line.
- Acceleration = 0.

(B) Uniform Acceleration

- Straight line with positive slope.

Slope = Acceleration

$$\boxed{\text{Slope} = \frac{\Delta v}{\Delta t} = a}$$

(C) Uniform Retardation

- Straight line with negative slope.

Acceleration is negative.

Area under Velocity–Time Graph

The area under a velocity–time graph gives the **displacement**.

$$\boxed{\text{Displacement} = \text{Area under the } v\text{-}t \text{ graph}}$$

This is one of the most important concepts in CBSE, NEET, and JEE.

---

7. Acceleration–Time (a–t) Graph

An acceleration–time graph represents the variation of acceleration with time.

Constant Acceleration

- Horizontal line parallel to the time axis.

Variable Acceleration

- Curved or irregular graph.

Area Under Acceleration–Time Graph

The area under an acceleration–time graph gives the **change in velocity**.

$$\boxed{\Delta v = \text{Area under the } a\text{-}t \text{ graph}}$$

---

8. Solved Examples

Example 1

A car increases its velocity from **10 m s^{-1}** to **30 m s^{-1}** in **5 s**. Find the acceleration.

Solution

a = (30−10) / 5 = 20 / 5 = 4 ms^{-2}

Answer: 4 m s^{-2}

Example 2

A motorcycle slows down from **18 m s^{-1}** to **6 m s^{-1}** in **4 s**. Find the retardation.

Solution

A = (6−18) / 4 = −3 m s^{-1}

Answer: Retardation = **3 m s^{-2}**

Example 3

A particle moves with constant velocity. What is its acceleration?

Answer:

$$\boxed{a = 0}$$

---

9. Summary Table

Graph	Slope Represents	Area Represents
Position–Time	Velocity	No direct physical meaning
Velocity–Time	Acceleration	Displacement
Acceleration–Time	No direct physical meaning	Change in Velocity

---

10. Exam Tips (★★★★★)

- **Slope of x–t graph = Velocity.**
- **Slope of v–t graph = Acceleration.**
- **Area under v–t graph = Displacement.**
- **Area under a–t graph = Change in Velocity.**
- A horizontal line in the **v–t graph** indicates **constant velocity**.
- A horizontal line in the **a–t graph** indicates **constant acceleration**.

Part – 4 : Equations of Motion (SUVAT Equations) and Their Derivations

Learning Objectives

After studying this part, you will be able to:

- Derive the three equations of uniformly accelerated motion.
- Understand the conditions under which these equations are applicable.
- Solve numerical problems using the equations of motion.
- Interpret the equations graphically.

---

1. Conditions for Applying the Equations of Motion

The three equations of motion are valid only when:

- Motion is along a **straight line**.
- **Acceleration is constant (uniform)**.
- SI units are used consistently.

If acceleration is variable, these equations are **not applicable**.

---

2. Standard Symbols (SUVAT Notation)

Symbol	Physical Quantity	SI Unit
u	Initial velocity	m s^{-1}
v	Final velocity	m s^{-1}
a	Uniform acceleration	m s^{-2}
t	Time	s
s	Displacement	m

Deriving the three Equations of Motion by Algebra Method

3. First Equation of Motion

Starting from the definition of acceleration,

$$a = \frac{v-u}{t}$$

Rearranging,

$$at = v - u$$

Hence,

$$\boxed{v = u + at}$$

Interpretation

- If a > 0, velocity increases with time.
- If a < 0, velocity decreases with time.

---

4. Second Equation of Motion

Average velocity for uniform acceleration is

$$Average\ velocity = \frac{u+v}{2}$$

Displacement,

$$s = \frac{(u+v)t}{2}$$

Substitute v = u + at,

$$s = \frac{(u+u+at)t}{2}$$

Therefore,

$$\boxed{s = ut + \frac{1}{2}at^2}$$

5. Third Equation of Motion

From

$$v = u + at$$

we get

$$t = \frac{v-u}{a}$$

Substitute this into

$$s = \frac{(u+v)t}{2}$$

After simplification,

$$\boxed{v^2 = u^2 + 2as}$$

This equation does **not** contain time.

6. Summary of the Three Equations

$$\boxed{v = u + at}$$

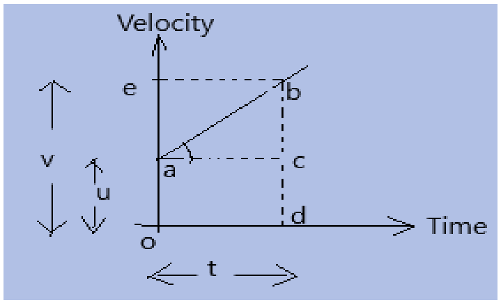
$$\boxed{s = ut + \frac{1}{2}at^2}$$

$$\boxed{v^2 = u^2 + 2as}$$

These are collectively called the **SUVAT Equations**.

7. Graphical Derivation

(A) To derive First Equation



Let a particle with initial velocity u starting at t = 0 with uniform acceleration and after time t, its final velocity becomes v. A graph is shown between velocity and time in the adjacent figure.

From the **velocity–time graph**,

Here, oa = u = cd, oe = v = bd, od = t = ac, bc = bd – cd = v-u

The slope of velocity-time graph represents acceleration (a).

$$a = slope\ of\ Line\ ab = \frac{bc}{ac} = \frac{v-u}{t}$$

Or,

$$v - u = at$$

Or,

$$\boxed{v = u + at}$$

Derived

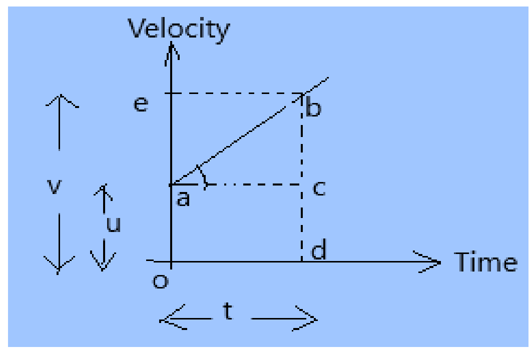
(B) To Derive Second Equation

Displacement = Area under the velocity–time graph.
Area = Rectangle + Triangle,
From the **velocity–time graph**,
Here, oa = u = cd, oe = v = bd, od = t = ac, bc = bd – cd = v-u
So,

$$Displacement\ (s) = Area\ of\ rectangle\ oacd + area\ of\ triangle\ abc$$

Or,

$$s = oa \times od + \frac{1}{2} \times ac \times bc$$



Or,

$$s = ut + \frac{1}{2}t \times (v - u)$$

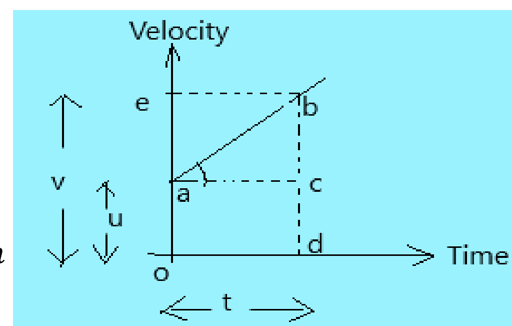
By putting, $v = u + at$, we get
$s = ut + \frac{1}{2}t \times (u + at - u) = ut + \frac{1}{2}at^2$
Hence,

$$\boxed{s = ut + \frac{1}{2}at^2}$$

Derived

(C) Third Equation

Using the area under the velocity–time graph together with
v= u + at
Here,
From the **velocity–time graph**,
Here, oa = u = cd, oe = v = bd, od = t = ac, bc = bd – cd = v-u
So,



$$displacement = area\ of\ trapezium$$
$$= \frac{1}{2}(oa + bd) \times od$$

Or,

$$s = \frac{1}{2}(u + v) \times t - - - - (i)$$

And from the graph, acceleration = slope, so

$$slope = a = \frac{bc}{ac} = \frac{v-u}{t}$$

Or,

$$t = \frac{v - u}{a}$$

By putting the value of t in equation (i), we get

$$s = \frac{(v + u)(v - u)}{2a}$$

Or,

$$v^2 - u^2 = 2as$$

Or,

$$\boxed{v^2 = u^2 + 2as}$$

Derived

---

8. Deriving Three Equations of Motion by Calculus Method

(A)To derive

$$\boldsymbol{v = u + at}$$

Let a particle moves in straight line with initial velocity u and uniform acceleration a. After time t, its final velocity becomes v. Then,
Limits are:

$$At, t = 0, v = u; At\ t = t, v = v$$

By using Calculus,

$$a = \frac{dv}{dt}$$

Or,

$$dv = adt \, -- (i)$$

Integrating equation (i) both sides with limit, we get,

$$\int_u^v dv = \int_{t=0}^{t=t} adt$$

Or,

$$(v)_u^v = a(t)_0^t$$

Or,

$$v - u = a(t - 0)$$

Or,

$$\boxed{v = u + at}$$

Derived

(B)To derive

$$s = ut + \frac{1}{2}at^2$$

Let a particle starts from initial velocity u with uniform acceleration a in a straight line path.. After time t, it covers the displace s. Then,
Limits are:

$$At\ t = 0, s = 0, At\ t = t, s = s$$

By using Calculus,

$$v = \frac{ds}{dt}$$

Or,

$$ds = vdt - - - (i)$$

Integrating equation (i) both sides with limits, we get,

$$\int_{s=0}^{s=s} ds = \int_{t=0}^{t=t} vdt - - - - (ii)$$

Putting, $v = u + at$ in equation (ii), we get

$$\int_0^s ds = \int_0^t (u + at)dt = \int_0^t udt + atdt$$

Or,

$$[s]_0^s = \left[ut + \frac{1}{2}at^2\right]_0^t$$

Or,

$$s = ut + \frac{1}{2}at^2 - 0 - 0$$

Or,

$$\boxed{s = ut + \frac{1}{2}at^2}$$

Derived

(C)To derive

$$v^2 = u^2 + 2as$$

Let a particle is moving on a straight line path with initial velocity v and uniform acceleration a. After time t, its final velocity becomes v and covers the displacement s.
Then,

$$At\ t = 0, v = u, s = 0; At\ t = t, v = u\ and\ s = s$$

Using the Calculus method,

$$a = \frac{dv}{dt}\ and\ v = \frac{ds}{dt}$$

Therefore,

$$a = \frac{dv}{ds} \times \frac{ds}{dt} = v\frac{dv}{ds}$$

Or,

$$vdv = ads - - - - (i)$$

Integrating equation (i) both sides with limits, we get,

$$\int_u^v vdv = \int_0^s ads$$

Or,

$$\left(\frac{v^2}{2}\right)_u^v = a(s)_0^s$$

)r,

$$\frac{v^2 - u^2}{2} = as$$

Or,

$$\boxed{v^2 = u^2 + 2as}$$

Derived

9. Special Cases

Case 1: Body Starts from Rest

$$\boldsymbol{u = 0}$$

Then,

$$v = at$$
$$s = \frac{1}{2}at^2$$
$$v^2 = 2as$$

Case 2: Body Comes to Rest

$$\boldsymbol{v = 0}$$

Then,

$$0 = u + at$$

Or,

$$a = -\frac{u}{t}$$

Negative acceleration indicates **retardation**.

---

10. Solved Examples

Example 1

A car starts from rest and accelerates uniformly at **2 m s⁻²** for **10 s**. Find the final velocity.

Solution

Given:

$$u = 0$$

So,

$$v = u + at$$

Or,

$$v = at = (2)(10) = 20$$

Answer: 20 m s⁻¹

Example 2

A train moves with an initial velocity of **10 m s⁻¹** and accelerates at **3 m s⁻²** for **5 s**. Find the displacement.

Solution

Using

$$s = ut + \frac{1}{2}at^2$$

So,

$$s = 10 \times 5 + \frac{1}{2}(3)(25) = 87.5$$

Answer: 87.5 m

Example 3

A particle moves from **5 m s⁻¹** to **25 m s⁻¹** with an acceleration of **4 m s⁻²**.
Find the displacement.

Solution
Using

$$v^2 = u^2 + 2as$$

So,

$$625 = 25 + 2 \times 4 \times s$$

Or,

$$s = 75m$$

Answer: 75 m

---

11. Common Mistakes

□ Applying the equations when acceleration is variable.
✔ Use them **only for uniform acceleration**.

□ Forgetting the sign of acceleration.
✔ Take **positive** acceleration for speeding up and **negative** acceleration for retardation.

□ Mixing SI and non-SI units.
✔ Convert all quantities to SI units before calculation.

---

12. Exam Tips (★★★★★)

- Memorize all **three equations of motion**.
- Learn **both algebraic and graphical derivations**.
- Remember the **conditions of applicability**.
- Draw neat **velocity–time graphs** in derivation questions.
- Check the sign of acceleration carefully in numerical problems.

Part – 5: Motion under Gravity (Free Fall and Vertical Motion)

Learning Objectives

After studying this part, you will be able to:

- Understand the concept of free fall.
- Define acceleration due to gravity.
- Apply equations of motion to vertically moving bodies.
- Analyze upward and downward motion.
- Solve numerical problems based on free fall.

---

1. Motion Under Gravity

When an object moves **only under the influence of Earth's gravitational force**, its motion is called **motion under gravity**.

Examples:

- A stone dropped from a building.
- A ball thrown vertically upward.
- A fruit falling from a tree.

In such cases, the acceleration remains constant and is equal to the acceleration due to gravity.

---

2. Acceleration Due to Gravity (g)

Definition

The acceleration produced in a freely falling body due to Earth's gravitational attraction is called **acceleration due to gravity**.

Symbol

$$\boxed{g}$$

SI Unit

$$\boxed{\mathrm{m\ s^{-2}}}$$

Dimensions

$$\boxed{[LT^{-2}]}$$

Standard Value

Near the Earth's surface,

$$\boxed{g = 9.8\ \mathrm{m\ s^{-2}}}$$

For numerical problems (unless otherwise specified),

$$\boxed{g \approx 9.8\ \mathrm{m\ s^{-2}}\ \text{or} 10\ \mathrm{m\ s^{-2}}}$$

---

3. Free Fall

Definition

A body is said to be in **free fall** when it moves only under the influence of gravity, neglecting air resistance.

Characteristics

- Acceleration is constant.
- Acceleration is directed vertically downward.
- The mass of the object does not affect the acceleration (ignoring air resistance).

---

4. Equations of Motion Under Gravity

The usual equations of motion remain valid by replacing a with g.

For Downward Motion (Taking Downward as Positive)

$$\boxed{v = u + gt}$$

$$\boxed{\boldsymbol{h = ut + \frac{1}{2}gt^2}}$$

$$\boxed{v^2 = u^2 + 2gh}$$

For Upward Motion (Taking Upward as Positive)

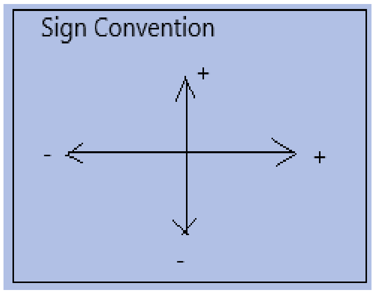
Since gravity acts downward,

$$a = -g$$

Therefore,

$$\boxed{v = u - gt}$$

$$\boxed{h = ut - \frac{1}{2}gt^2}$$



$$v^2 = u^2 - 2gh$$

Note: Clearly mention the chosen sign convention before solving numerical problems.

---

5. Body Dropped from Rest

If a body is dropped (not thrown),

$$u = 0$$

Hence,

$$\boxed{v = gt}$$

$$\boxed{h = \frac{1}{2}gt^2}$$

$$\boxed{v^2 = 2gh}$$

---

6. Body Thrown Vertically Upward

When a body is thrown upward:

- Initial velocity is upward.
- Acceleration is always downward (−g).
- Velocity decreases uniformly.
- At the highest point,

$$\boxed{v = 0}$$

Maximum Height

Using

$$v^2 = u^2 - 2gh$$

At the highest point,

$$v = 0$$

Therefore,

$$\boxed{h = \frac{u^2}{2g}}$$

Time of Ascent

Using

$$v = u - gt$$

At the highest point,

$$0 = u - gt$$

Hence,

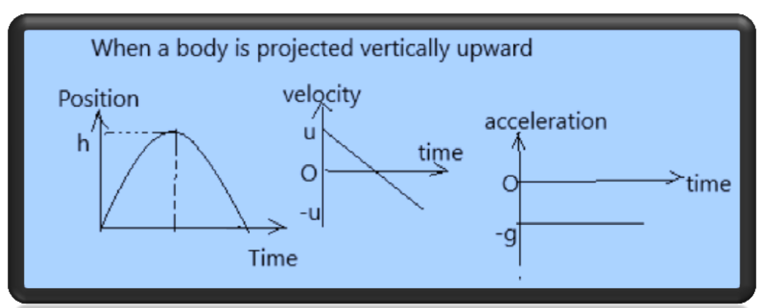
$$\boxed{t = \frac{u}{g}}$$

Total Time of Flight

For a body returning to the same level,

$$\boxed{T = \frac{2u}{g}}$$

7. Velocity–Time Graph for Vertical Motion



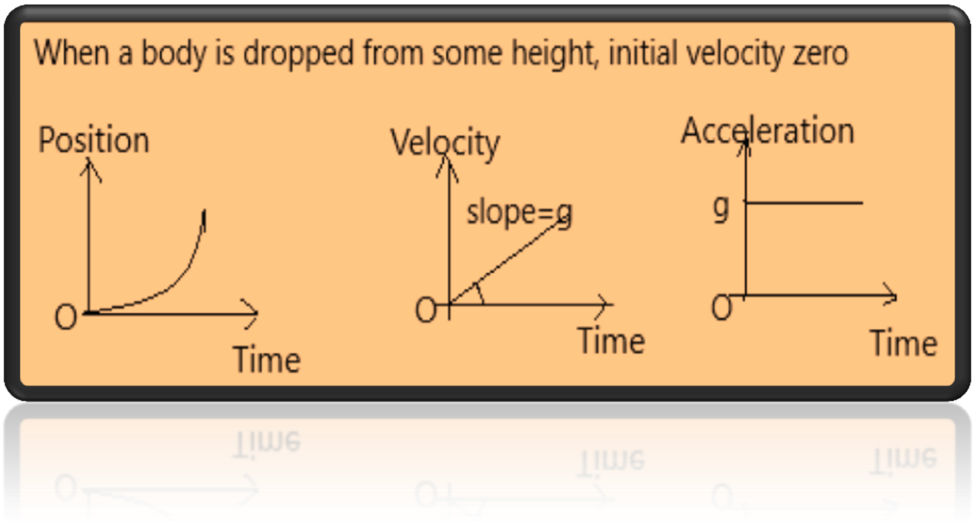
Upward Motion

- Velocity decreases linearly with time.
- Slope = −g

Downward Motion

- Velocity increases linearly with time.

- Slope = +g (if downward is taken as positive).



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8. Solved Examples

Example 1

A stone is dropped from rest. Find its velocity after **3 s**.

Solution

Given:

$$u = 0, t = 3s, g = 9.8\, ms^{-2}$$

Using

$$v = u + gt$$
$$v = 0 + 9.8 \times 3 = 29.4$$

Answer: 29.4 m s⁻¹ downward

Example 2

A ball is thrown vertically upward with a speed of **19.6 m s⁻¹**.
Find the maximum height.

Solution

Using

$$h = \frac{u^2}{2g}$$
$$h = \frac{(19.6)^2}{2 \times 9.8} = 19.6\, m$$

Answer: 19.6 m

Example 3

A ball is thrown upward with an initial velocity of **20 m s⁻¹**.
Take g = 10 m s^{-2}
Find:
(a) Time to reach the highest point

(b) Maximum height

Solution

(a)

$$t = \frac{u}{g} = \frac{20}{10} = 2\ s$$

(b)

$$h = \frac{u^2}{2g} = \frac{(20)^2}{2 \times 10} = 20\ m$$

Answer:

- Time of ascent = **2 s**
- Maximum height = **20 m**

---

9. Common Mistakes

□ Assuming acceleration becomes zero at the highest point.
✔ At the highest point, **velocity is zero**, but **acceleration remains equal to g** downward.

□ Changing the sign of g incorrectly.
✔ Always define the positive direction before solving.

✔ Use the value given in the question.

---

10. Exam Tips (★★★★★)

- The **acceleration due to gravity is always downward**, regardless of whether the object is moving upward or downward.
- At the **highest point**, only the **velocity becomes zero**; acceleration does **not** become zero.
- Clearly mention the **sign convention** in vertical motion problems.
- Questions on **maximum height**, **time of ascent**, and **time of flight** are frequently asked in **CBSE, NEET, and JEE**.

Part – 6: Graphical Analysis

1. Graphical Analysis of Motion

Graphs are powerful tools to understand motion.
The three important graphs are:

1. Position–Time (x–t) graph
2. Velocity–Time (v–t) graph
3. Acceleration–Time (a–t) graph

---

2. Position–Time Graph

Slope gives velocity

Slope of x-t graph = v

Different Cases

(a) Horizontal Line

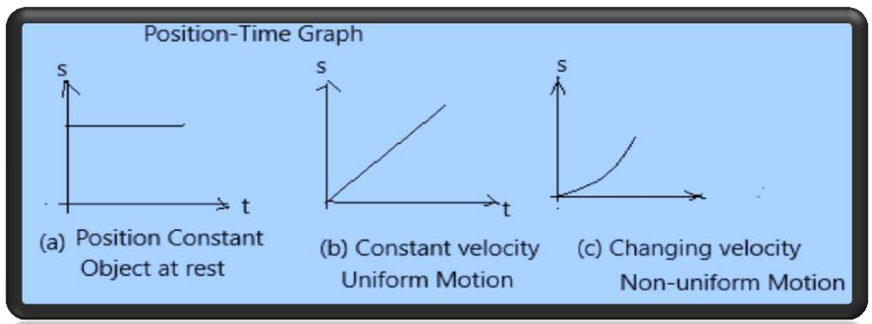
- Position constant.
- Object at rest.

(b) Straight Inclined Line

- Constant velocity.
- Uniform motion.

(c) Curved Line

- Changing velocity.
- Non-uniform motion.



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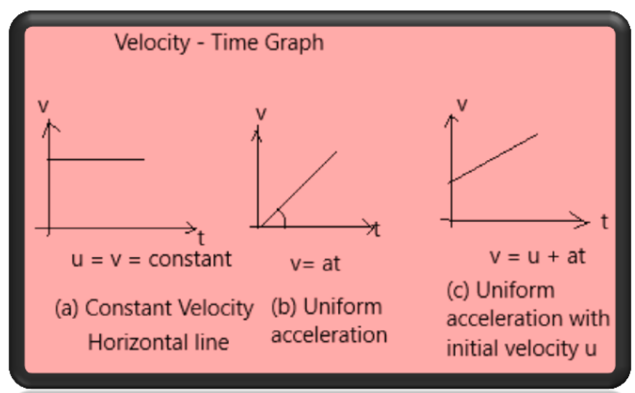
3. Velocity–Time Graph

Slope gives acceleration

Slope of v-t graph = a

Area gives displacement

Area under v-t graph = s



Cases:

Constant Velocity

Horizontal line.

$$a = 0$$

Uniform Acceleration

Straight line with positive slope.

$$a > 0$$

Uniform Retardation

Straight line with negative slope.

$$a < 0$$

4. Acceleration–Time Graph

Area gives change in velocity

Δv = Area under a-t graph

5. Important Graphical Questions

Q1. What does the slope of a velocity-time graph represent?

Answer:
Acceleration

Q2. What does the area under a velocity-time graph represent?

Answer:
Displacement

Q3. A horizontal line in velocity-time graph represents?

Answer:
Uniform velocity

6. Quick Revision Table

Concept	Formula
Slope of x–t graph	Velocity
Slope of v–t graph	Acceleration
Area of v–t graph	Displacement
Area of a–t graph	Change in velocity

7. Exam Tips (★★★★★)

- Always choose a positive direction before solving relative motion problems.
- For opposite directions, relative velocity is the **sum of velocities**.
- For same directions, relative velocity is the **difference of velocities**.
- Remember:
  - Slope → Rate of change
  - Area → Accumulated quantity

Part – 7: Important Applications, Advanced Numerical, Common Mistakes & Complete Concept Revision

Learning Objectives

After completing this part, you will be able to:

- Apply all concepts of one-dimensional motion.
- Solve NCERT, CBSE, NEET and JEE level problems.
- Identify common mistakes in numerical problems.
- Revise the complete chapter quickly.

---

1. Important Applications of Motion in a Straight Line

Motion in a straight line is applied in:

- Falling objects under gravity.
- Motion of vehicles on straight roads.
- Motion of trains.
- Motion of lifts.
- Rocket motion during initial stages.
- Measurement of speed and acceleration.

---

2. Important Concepts Revision

(A) Distance and Displacement

Distance

$$\boxed{\text{Distance} = \text{Total path length}}$$

Scalar quantity

- Always positive
- Depends on actual path

Displacement

$$\boxed{\Delta x = x_f - x_i}$$

- Vector quantity
- Can be positive, negative or zero

---

3. Speed and Velocity

Speed

$$\boxed{\text{Speed} = \frac{\text{Distance}}{\text{Time}}}$$

Velocity

$$\boxed{\text{Velocity} = \frac{\text{Displacement}}{\text{Time}}}$$

---

4. Acceleration

$$\boxed{a = \frac{v-u}{t}}$$

Where:

- u = Initial velocity
- v = Final velocity
- t = Time

---

5. Equations of Motion

For uniformly accelerated motion:

First Equation

$$\boxed{v = u + at}$$

Second Equation

$$\boxed{s = ut + \frac{1}{2}at^2}$$

Third Equation

$$\boxed{v^2 = u^2 + 2as}$$

---

6. Motion Under Gravity

Acceleration:

$$\boxed{g = 9.8\ \text{m s}^{-2}}$$

Falling Body

$$v = u + gt$$

Upward Projection

$$h = ut + \frac{1}{2}gt^2$$

---

7. Important Solved Numerical

Problem is based on calculus method to find s, v and a.

Numerical 1:

A particle is moving is moving with a velocity of $v = (3 + 6t + 9t^2)$ m/s. Find out the:

(a) acceleration of the particle at t = 3 s,
(b) the displacement of the particle in the interval of t = 5s to t = 8s.
(c) average acceleration of the particle between t = 5 s and t = 8s

Solution:

(a) acceleration at t = 3s, using

$$a = \frac{dv}{dt}$$

Then,

$$a = \frac{d(3 + 6t + 9t^2)}{dt} = 6 + 18t = 6 + 18(3) = 60\, ms^{-2}$$

Answer: 60 m $s^{=2}$

(b) Displacement between 5s and 8s

$$\int_{s_1}^{s_2} ds = \int_{t_1}^{t_2} v dt$$

Then,

$$\int_{s_1}^{s_2} ds = \int_{5}^{8} (3 + 6t + 9t^2) dt\ Or, (s_2 - s_1) = [3t + 3t^2 + 3t^3]_5^8$$

Or,

$$(s_2 - s_1) = [(3 \times 8 + 3 \times 64 + 3 \times 512) - (3 \times 5 + 3 \times 25 + 3 \times 125)]$$

Or,

$$(s_2 - s_1) = 3(584 - 155) = 3 \times 429 = 1287\, m$$

Answer: 1287 m

(c) Average acceleration between 5 s and 8s,

At t = 5 s,

$$v_1 = 3 + 6 \times 5 + 9 \times 25 = 258\, m/s$$

And, at t = 8s,

$$v_2 = 3 + 6 \times 8 + 9 \times 64 = 636\, m/s$$

Average acceleration,

$$a_{av} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{(636) - (258)}{8 - 5} = \frac{378}{3} = 126\, ms^{-2}$$

Answer: 126 ms^{-2}

Problem based on distance and displacement when the particle is thrown upwards and then coming down

Numerical 2:

A particle is projected vertically upwards with velocity 40 m/s. Find the displacement and distance travelled by the particle in (a) 2s, (b) 4 s, (c) 6s; Take g = 10 ms^{-2}.

Solution:

We know that distance = displacement when u = 0 or u parallel to a. If u is antiparallel to a, then $d \neq s$. Also, a = - g

When the particle is projected vertically upwards, the final velocity is zero. Here, we will find first the time upto which u $\uparrow\uparrow$ a, Then, by using

$$v = u - gt$$

$$0 = 40 - 10t$$

Or,

$$t = \frac{40}{10} = 4\ s$$

Therefore, up to t = 4 s, distance (d) = displacement (s). Beyond t = 4 s, d > s.

(a) At, t = 2s,

$$d = s = ut - \frac{1}{2}gt^2$$

Or,

$$d = s = 40 \times 2 - \frac{1}{2} \times 10 \times 4 = 80 - 20 = 60\ m$$

Answer: d = s = 60 m

(b) At, t = 4 s, again,

$$d = s = ut - \frac{1}{2}gt^2$$

Or,

$$d = s = 40 \times 4 - \frac{1}{2} \times 10 \times 16 = 160 - 80 = 80\ m$$

Answer: d = s = 80 m

(c) At, t = 6 s,

$$d \neq s\ as\ t > 4\ s$$

So,

$$distance\ d = d_1 + d_2$$

Here, d_1 can be calculated as: up to 4s, ($a \uparrow\downarrow g$) (upward motion)

$$d_1 = ut - \frac{1}{2}gt^2$$

Or,

$$d_1 = 40 \times 4 - \frac{1}{2} \times 10 \times 16 = 160 - 80 = 80\ m$$

Now, next for t = 2 s, $a \uparrow\uparrow g$ (downward motion), u = 0

$$d_2 = ut + \frac{1}{2}gt^2$$

Or,

$$d_2 = 0 \times 2 + \frac{1}{2} \times 10 \times 4 = 0 + 20 = 20\ m$$

Hence,

$$distance\ (d) = d_1 + d_2 = 80 + 20 = 100\ m$$

Answer: distance covered in 6 s, is 100 m

For, displacement at t = 6 s, we apply the formula,

$$s = ut - \frac{1}{2}gt^2$$

So,

$$s = 40 \times 6 - \frac{1}{2} \times 10 \times 36 = 240 - 180 = 60\ m$$

Answer: displacement at t = 6 s: 60 m

Numerical 3:

A ball is thrown upwards from the top of a tower 40 m high with a velocity of 10 m/s. Find the time taken when it strikes the ground. Take g = 10 ms^{-2}.

Solution:

By the sign convention, height of tower will be taken negative. The ball is thrown from the top of the tower, that will be base line. So,

$$h = -40\ m; u = 10\ m/s$$

Now the ball is falling down, so, a = g, applying,

$$h = ut + \frac{1}{2}gt^2$$

Hence,

$$-40 = 10t - 5t^2$$

This is a quadratic equation. Applying,

$$ax^2 + bx + c = 0$$

Then,

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

We get,

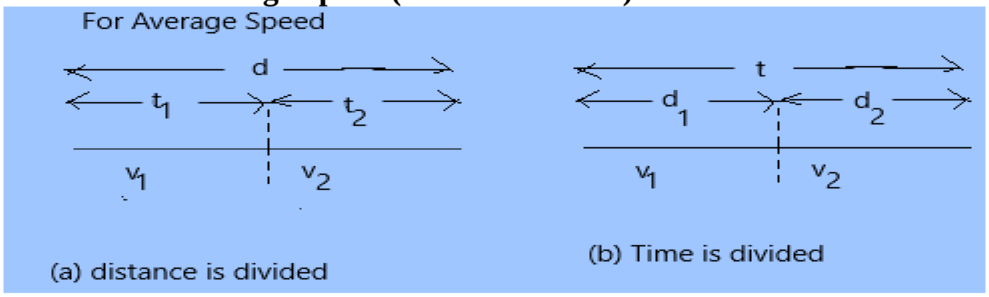
$$t^2 - 2t - 8 = 0, Or\ t = \frac{2 \pm \sqrt{4 + 4 \times 1 \times 8}}{2} = \frac{2 \pm \sqrt{36}}{2}$$

Since, time is not negative, hence, we will take,

$$t = 1 + 3 = 4\ s$$

Answer: 4 s

Numerical based on Average Speed (Uniform motion)



Numerical 4:

A particle travels first half of the total time with constant speed v_1 and second half time with constant speed v_2. Find the average speed during the complete journey.

Solution:

Here time is divided and divided equally. So, we apply,

$$Average\ speed\ (v_{av}) = \frac{v_1 + v_2}{2}$$

As,

$$[Average\ speed = \frac{Total\ distance}{Total\ time} = \frac{d_1 + d_2}{t_1 + t_2} = \frac{v_1\frac{t}{2} + v_2\frac{t}{2}}{\frac{t}{2} + \frac{t}{2}} = \frac{v_1 + v_2}{2}]$$

Numerical 5:

A particle travels first half of the total distance with constant speed v_1 and second half with constant speed v_2. Find the average speed during the complete journey.

Solution:

Here distance is divided and divided equally. So, we apply,

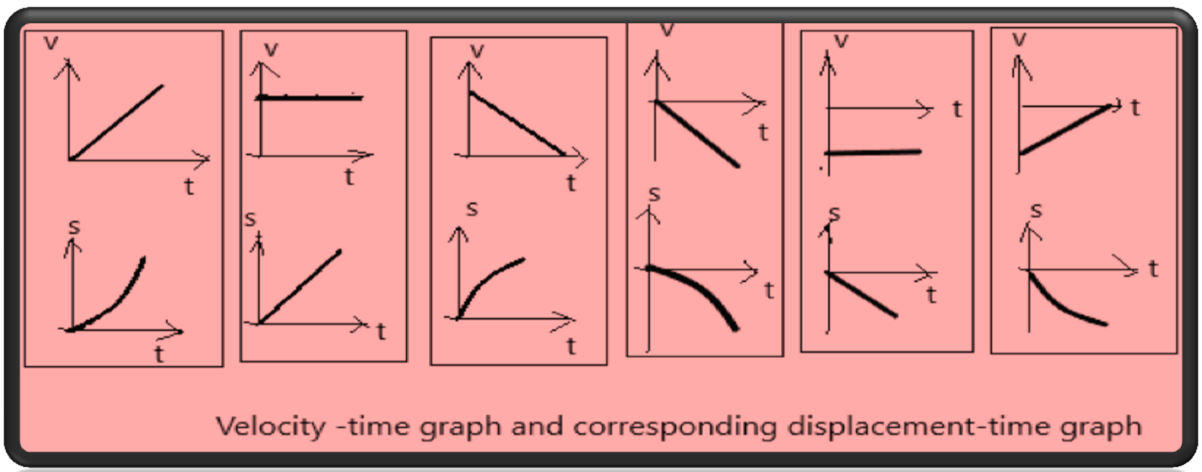
$$Average\ speed\ (v_{av}) = \frac{2v_1v_2}{v_1 + v_2}$$

As,

$$[Average\ speed = \frac{Total\ distance}{Total\ time} = \frac{d_1 + d_2}{t_1 + t_2} = \frac{d}{\frac{d}{2v_1} + \frac{d}{2v_2}} = \frac{2v_1v_2}{v_1 + v_2}]$$

To find s-t graph and a-t graph from v-t graph.

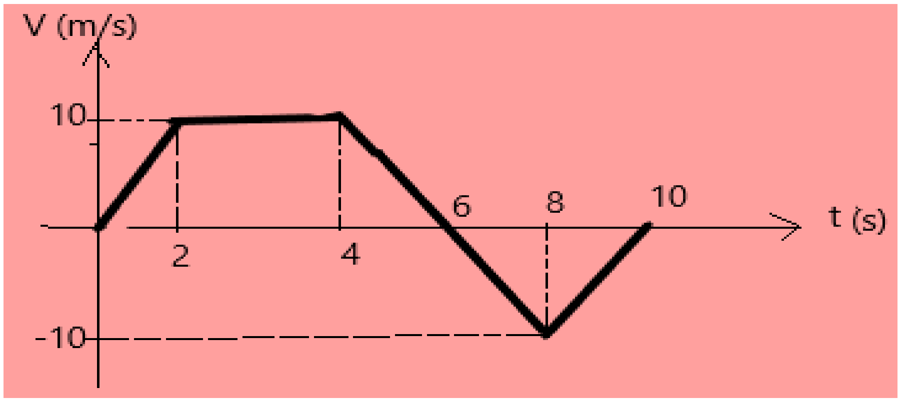
From v-t graph to s-t graph, we do integration. Suppose, $v \propto t(straight\ Line), we\ get\ s \propto t^2$ (parabola) and from v-t graph to a-t graph, we do differentiation. Suppose $v \propto t, a = constant$. The below graph shows how a v-t graph can be converted into a s-t graph just for indication. The actual s-t graph can be different from a v-t graph depending upon the data in graph. An example is taken below.



Velocity -time graph and corresponding displacement-time graph

Numerical 6:

Velocity-time graph of a particle moving in a straight line is shown in the figure. At time t = 0 s, displacement x = - 10 m. Plot corresponding x-t and a-t graph and also calculate average velocity and average speed of the particle.



Solution:

For making s-t graph, we know that the area under the v-t graph represents displacement. The below table shows how s-t graph can be drawn from the given data.

Given, initial displacement $x_i = -10\ m$

Table-1

Time Interval ((Δt) in seconds	$Area = \Delta x = displacement\ in\ m$	$x_f = x_i + \Delta x$ (in m)
0-2	**10**	$x_{f_1} = -10 + 10 = 0$
2-4	**20**	$x_{f_2} = 0 + 20 = 20$
4-6	**10**	$x_{f_3} = 20 + 10 = 30$
6-8	**-10**	$x_{f_4} = 30 - 10 = 20$
8-10	**-10**	$x_{f_5} = 20 - 10 = 10$
Total time = 10 s	**Total displacement = 20 m**	
	Total distance = 60 m	

Note: Area above the time axis is taken positive and area below the time axis is taken negative.

The corresponding x-t graph is shown below in Fig-(a).

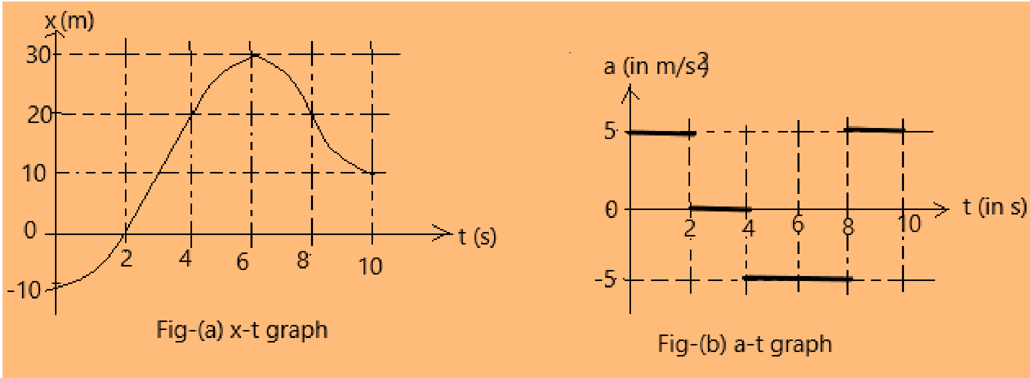
For a-t graph, the corresponding table is shown below.

Since the slope of v-t graph represents the acceleration, the a-t graph can be drawn based on below data in the table-2.

Table-2

Time interval (Δt) in seconds	$slope = acceleration = \frac{v_f - v_i}{t_f - t_i}$ (in ms^{-2})
0-2	$= \frac{10-0}{2-0} = 5$
2-4	$= \frac{10-10}{4-2} = 0$
4-6	$= \frac{0-10}{6-4} = -5$
6-8	$= \frac{-10-0}{8-6} = -5$
8-10	$= \frac{0-(-10)}{10-8} = 5$

The corresponding graph is shown in Fig-(b) below.



Now, for calculation of Average velocity and average speed-
Average speed,

$$\boldsymbol{average\ speed = \frac{Total\ distance}{Total\ time}}$$

From the table-1:

$$\boldsymbol{average\ speed = \frac{60}{10} = 6\ m/s}$$

And,

$$\boldsymbol{average\ velocity = \frac{Total\ displacement}{Total\ time}}$$

Hence,

$$\boldsymbol{average\ velocity = \frac{20}{10} = 2\ m/s}$$

8. Important Graph Concepts

Position–Time Graph

Slope:

Velocity

Velocity–Time Graph

Slope:

Acceleration

Area:

Displacement

Acceleration–Time Graph

Area:

Change in Velocity

---

9. Common Mistakes to Avoid

Mistake 1

Using distance instead of displacement for velocity.

✔ Velocity always uses displacement.

Mistake 2
Using equations of motion for variable acceleration.
✔ Equations are valid only for uniform acceleration.

Mistake 3
Ignoring direction.
✔ Motion problems require proper sign convention.
Mistake 4
At maximum height, assuming acceleration is zero.
✔ Only velocity becomes zero; acceleration remains g.

Mistake 5
Confusing speed and velocity.
✔ Speed has no direction; velocity has direction.

---

10. Important NCERT-Based Questions

Q1.
Can an object have zero velocity but non-zero acceleration?
Answer:
Yes. At the highest point of upward motion, velocity is zero but acceleration is g.

Q2.
Can displacement be greater than distance?
Answer:
No.

$$\boxed{\text{Distance} \geq \text{Displacement}}$$

Q3.
Can acceleration be negative while velocity is positive?
Answer:
Yes. Example: A car slowing down while moving forward.

---

11. NEET/JEE Important Points

☐ Distance is always scalar.
☐ Displacement can be zero even when distance is not zero.
☐ Velocity is the slope of x–t graph.
☐ Acceleration is the slope of v–t graph.
☐ Area under v–t graph gives displacement.
☐ The sign of acceleration depends on the chosen direction.
☐ Free fall acceleration is independent of mass.

---

12. Chapter 2 Final Concept Map

```
Motion in a Straight Line
              │
              ├── Position
              │
              ├── Distance & Displacement
              │
              ├── Speed & Velocity
              │
              ├── Acceleration
              │
              ├── Motion Graphs
              │
              ├── Equations of Motion
              │
              ├── Free Fall
              │
```